SPATIAL ANALYSIS OF ATRAZINE

IN THE ELM FORK WATERSHED

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This study assessed the water quality of the Elm Fork Watershed with regards to the herbicide Atrazine. Atrazine is a potential environmental endocrine disruptor and carcinogen. Overall, concentrations were lower than the four-quarter drinking water average of 3 µg/L—the Maximum Contaminant Level set by the USEPA. However, three creek stations had four-quarter average concentrations greater than 3 µg/L, and virtually all samples exceeded the 0.1 µg/L standard set in Europe [1,2]. Statistically significant differences in concentrations were detected between the 27 sampling stations and areas of high concentrations were identified. However correlations between Atrazine concentrations and land-use and precipitation were not statistically significant. Further analysis with more detailed data should be conducted before any relationships are discarded.

INTRODUCTION

General Information

The herbicide Atrazine, $C_8H_{14}ClN_5$, is one of the two most widely used agricultural pesticides in the United States [3] and the most popular herbicide in U.S. corn and sorghum production [4]. Developed by the Swiss chemical company Ciba-Geigy (now Novartis) in the 1950's, it was introduced to U.S. farmers in 1959 [4], and it has been used mainly in the production of corn and sorghum, but also in sugarcane, pineapple, Christmas tree, sod farms, and conifer reforestation plantings [4,5]. In the U.S. alone, 64 to 80 million pounds of Atrazine are used per year [4], with an average application rate of 1.3 pounds per acre. Even though Atrazine is a restricted-use herbicide, meaning that only certified applicators can use it and only for agricultural purposes, it is easily available in the Dallas-Fort Worth Metroplex in the lawn products Miracle-Gro Weed and Feed for St. Augustine Grass and Scotts Bonus S (D. Garrett, personal communication).

Benefits

Atrazine's success is due to the fact that while it is very effective in controlling unwanted weeds, it has virtually no side effects on the crops that it is set to protect [6]. Atrazine works by blocking the photosynthetic process of the target plants. However, tolerant crops, such as corn and sorghum, usually absorb and metabolize it before it produces any deleterious effects on them. Furthermore, Atrazine, or better yet distinct properties of these crops, allow farmers to apply Atrazine at any time during the preplanting, pre-emergent, or post-emergent phase of the crop cycle [6]. Along with the aforementioned benefits is the added bonus that Atrazine is available at very low costs, thus making it commercially attractive.

A study conducted by the United States Department of Agriculture and state universities under the National Agricultural Pesticide Impact Assessment Program (NAPIAP) estimated the economic impact that different scenarios of restricted Atrazine use would have on producers and consumers [4]. These scenarios included: 1) Limiting application rates to 1.5 pounds of active ingredient per acre on pre-emergent applications and 1 pound per acre on post-emergent applications; 2) Limiting application rates to 1 pound per acre on post-emergent applications and banning all other uses; 3) Banning all use of Atrazine; and 4) Banning all triazines—including Atrazine, Cyanazine, Ametryn, and Simazine). The results ranged from an $80 million loss in Scenario 1 to a $1.2 billion loss in Scenario 4. Corn prices would increase by 1 to 4 percent and sorghum by 3 percent. Furthermore, decreased Atrazine use would probably mean greater erosion and sedimentation due to increased cultivation and a greater dependency on other herbicides—many of which need further evaluation for their effectiveness and safety [4]. It is important to note, however, that this study does not take into account any cost involved in the treatment of possible Atrazine-related illnesses or the treatment to remove Atrazine from drinking water supplies.

Physicochemical Characteristics

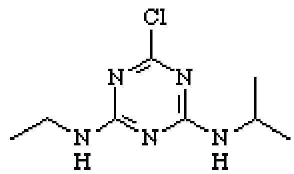


Figure 1—Molecular Structure of Atrazine [7]

Atrazine, Figure 1, is a white crystalline solid [5] that is available as a liquid, suspension concentrate, wettable powder, or water-dispersible granules [8]. Following field application, its low K_d (0.19-2.46) and K_{oc} (25-155) make it highly mobile in soils with low clay or organic matter content during irrigation and rain events [5,9]. Its lengthy environmental half-life (30 days–2 years) at neutral pHs and low volatilization potential (vapor pressure—2.89×10^{-7} mm @ 25C and Henry's Law constant—2.48×10^{-9} atm m^3 mol^{-1}) make Atrazine a high-risk surface and ground water pollutant since it will persist long enough to seep its way to the water table [5,9]. Once it reaches a water body, degradation is based mostly on chemical hydrolysis [5] due to its distinctive s-triazine ring, which makes it resistant to microbial degradation [9]. Besides Atrazine's vast usage and its persistence in nature, potential human and environmental health effects have made Atrazine a top research priority.

Toxicological Effects

Atrazine's acute toxicological effects are actually minimal [9]. Because of the way it works, by blocking photosynthesis, it is only toxic to organisms at very high concentrations. Chronic toxicity for non-plant species starts at around 30 µg/L for the most sensitive benthos, but in most cases it is at least one order of magnitude higher [9].

Chronic studies on dogs and rats show some long-term effects at concentrations of 7.5-mg/kg/day [5]. However, these are direct doses and they are still three orders of magnitude higher than concentrations found in the environment. An ecological risk assessment conducted by Solomon et al. determined that when matrix interactions were taken into account, no noticeable long-term effects on plants growth occurred following short exposures to concentrations below 20 µg/L—higher than the concentrations usually found in lakes and large streams [9].

Acute toxicity to mammals has been found to be at least 750 mg/kg (in rabbits), five orders of magnitude higher than environmental concentrations. Of course, humans with the greatest contact with Atrazine, as in the case of manufacturing workers and applicators, run the highest risk of being subjected to its toxicity. "Symptoms of poisoning include abdominal pain, diarrhea and vomiting, eye irritation, irritation of mucous membranes, and skin reactions" [5]. However, with precaution and the proper safety equipment, these acute problems can be easily avoided.

Atrazine as an Endocrine Disruptor and Carcinogen

The attention on Atrazine stems from its classification as an environmental endocrine disruptor (EED) by the EPA, the Center for Disease Control and Prevention, and the World Wildlife Fund [10]. Studies show that Atrazine—and chlorinated pesticides and herbicides in general (see Figure 1)—increases the chance for 17ß -estradiol metabolism to follow the 16□-hydroxyestrone (16□-OHE$_1$) pathway instead of the 2-hydroxyestrone (2-OHE$_1$) pathway [11,12]. In turn, an increased ratio of 16□-OHE$_1$ to 2-OHE$_1$ has been linked to higher risks of breast cancer [11,12,13]. Other studies have shown clastogenicity—damage of chromosomes and/or the whole cell—in

Chinese hamster ovary cells [14,15,16]. These later studies are of particular importance because the concentrations of Atrazine found to be clastogenic were as low as 3 μg/L. Another study, on rat intestinal and human colonic epithelial cell lines, showed growth-promoting effects by Atrazine [17]. Finally, a study by Munger et al. [18] established a slight correlation between Atrazine and intrauterine growth retardation in Iowa communities with elevated Atrazine concentrations in the drinking water supply.

Purpose and Objectives

Considering that breast cancer is the most common cancer and the second leading cause of death among females in the United States [19], it is important to take into account all the factors that might be influencing this epidemic. Cancer is usually not brought on by one single cause during one event, but by a lifetime exposure to different carcinogens that sooner or later lead stressed cells to mutate and grow uncontrollably [20]. For this reason, it is important to determine if Atrazine, at the levels that it is found in the environment, is liable to lead to cancer or endocrine disruption over a lifetime of drinking Atrazine-tainted water.

It is not the intent of this research to determine whether or not Atrazine is a carcinogen or an endocrine disruptor. Specific objectives of this project are to 1) estimate how much Atrazine is entering the drinking water supply of some cities in the Dallas-Fort Worth Metroplex; 2) detect where it is coming from; 3) determine how much of a relationship exists between land-use in the Elm Fork Watershed and Atrazine concentrations in creeks and rivers; and 4) detect which areas of the watershed have the highest potential for contributing Atrazine runoff into the reservoirs. This approach should facilitate any future watershed planning if Atrazine ever happens to be deemed as too much of a risk for either human or environmental health.

Hypotheses

The formal hypotheses that will be tested in this study are:

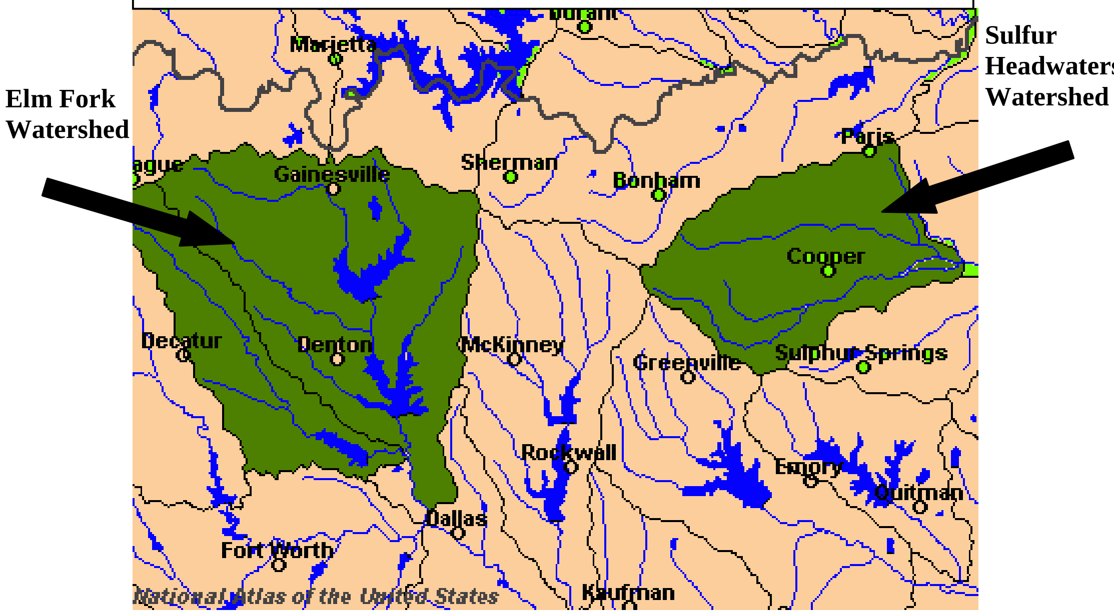
H_{01}: There is no difference in Atrazine concentration among the creeks in the Elm Fork Watershed.

H_{02}: There is no statistically significant correlation between land-use and Atrazine concentration in the streams of the Elm Fork Watershed.

H_{03}: There is no statistically significant correlation between precipitation and Atrazine concentrations in the Elm Fork Watershed.

DESCRIPTION OF STUDY AREA

Figure 2—Map of Study Area [21]



The Elm Fork Watershed lies in Northeast Texas between north latitudes 32º48’ and 33º44’ and west longitudes 96º45’ and 97º52’. It is actually comprised of two watersheds—the Elm Fork-Trinity Watershed (USGS Cataloguing Unit 12030103) where Lake Lewisville (29592 acres) [22] and Lake Ray Roberts (29350 acres) [23] are located, and the much smaller Denton Creek Watershed (USGS Cataloguing Unit 12030104) where Lake Grapevine (11460 acres) [24] is located. Together, they reside in eight counties, Collin, Cooke, Dallas, Denton, Grayson, Montague, Tarrant, and Wise and cover 2590 mi^2.

With a population of 2.35 million people, the cities of Denton, Lewisville, and Dallas consume most of the treated drinking water coming from Lake Lewisville. Denton and Dallas built Lake Ray Roberts in anticipation of future water needs and therefore own the rights to the water. This has forced other growing cities within the Metroplex, like Irving in Dallas County, to look for other water sources outside of the Elm Fork Watershed such as Chapman Lake in East Texas.

Since 1953 the City of Irving has been involved in the planning of Chapman Lake in its search for a reliable water source. Construction of the lake, then called Cooper Reservoir, began in 1964 and was completed in 1991, at which time filling began. Chapman Lake (22740 acres) [25] is located near the town of Cooper in the Sulfur Headwaters Watershed (USGS Cataloguing Unit 11140301). The watershed lies between north latitudes 33º08’ and 33º42’ and west longitudes 95º27’ and 96º12’ encompassing the counties of Delta, Fannin, Hopkins, Lamar, and Hunt and a total area of 1160 mi^2.

There are no major population centers in the area, and the main purpose of the lake is to supply water to the Dallas-Fort Worth Metroplex. The plan is to pump up to 62.59 million gallons a day into Lake Lewisville, 73 miles away. This will be made possible by an 84-inch diameter pipeline that will first deliver the water to Lake Lavon where a buster pump will send it the rest of the way via a 66-inch diameter pipeline to discharge in Doe Branch, which flows into Lake Lewisville. The first phase of the project, the pipeline into Lake Lavon, is complete and construction of Phase II will begin in the year 2000 with estimated completion by 2003 [26].

METHODS AND MATERIALS

Water Quality Analysis

Water quality data for this project has been collected quarterly since March 1998. Due to money constraints and the need to sample a large number of stations, sampling was conducted at long intervals. Therefore, results are only expected to be estimates of the water quality of the entire watershed. Collection dates were March 28, May 20, August 25, and November 21, 1998 and February 27, May 18, August 25, and December 18, 1999. There were a total of 27 sampling stations, Table 1, representing three types of water bodies: 1) streams—as close as possible to their inflow into the lakes; 2) lakes—near the discharge at the dam; and 3) drinking water samples from the different treatment plants in the Elm Fork Watershed.

Table 1- Atrazine Sampling Sites

Station	ID	Station	ID	Station	ID
Clear Creek	1	Spring/Indian Creek	10	Panther Creek	19
Elm Fork Below RR	2	Lake Ray Roberts	11	Doe Branch	20
Buck Creek	3	Hickory Creek	12	Little Elm	21
Range Creek	4	Denton Creek	13	Pecan Creek	22
Spring Creek	5	Lake Grapevine	14	Denton Tap	23
Timber Creek	6	Elm Fork South	15	Lewisville Tap	24
Indian Creek	7	Lake Lewisville	16	UTRWD	25
Wolf Creek	8	Stewart Creek	17	Grapevine Tap	26
Elm Fork Above RR	9	Cottonwood Branch	18	Chapman Lake	27

Samples were collected using a plastic bucket and stored in one liter amber bottles (with Teflon-lined caps). Three replicates were taken at each station. Air and water temperatures, conductivity, and dissolved oxygen were measured in the field at the time of the sampling. In the lab, samples were analyzed for pH, alkalinity, and hardness and stored at 4ºC immediately after returning from the field. Once all samples for the sampling period were collected, they were analyzed for Atrazine using an enzyme-linked immunosorbent assay (ELISA) kit.

The ELISA kits were purchased from Strategic Diagnostics Inc. (SDI) of Delaware a few days before each of the analyses were conducted in order to ensure the freshest reagents. The kits detect Atrazine concentrations from 0.1 µg/L to 5 µg/L. However, samples collected in this study were diluted to a 1:1 ratio with reverse-osmosis water to ensure that they would return a value within the detectable range. A more accurate alternative would have been to use gas chromatography-mass spectrometry (GC-MS), but the money and time involved with this type of analysis was prohibitive for this project. Furthermore, studies that compared the results from both analyses found that ELISA results corresponded reasonably well with GC-MS, especially at concentrations below 3 µg/L [27] and 5 µg/L [28].

The assay works by "combining antibodies attached to solid supports, with sensitive enzyme reaction, to produce analytical systems capable of detecting very low levels of chemicals [28]." Magnetic particles dispersed throughout the reagent are used as the solid support as well as the means for separating the chemicals of interest, in this case the triazines, from the remainder of the water sample [28].

Assay instructions called for adding 200 µL of sample to disposable polystyrene test tubes. Since the samples were diluted, 100 µL of sample was used instead as well as 100 µL of reverse-osmosis water—all other steps were conducted as instructed. A repeater pipette was used to add 250 μL of Atrazine Enzyme Conjugate (horseradish peroxidase) and 500 μL of Atrazine Antibody-Coupled Paramagnetic Particles (rabbit anti-Atrazine covalently bound to paramagnetic particles). The test tubes were then vortexed for two seconds and allowed to incubate for 15 minutes. Following the waiting period, a magnetic rack was used to separate the magnetic particles. After two minutes, the contents of the test tubes were poured and the tubes were inverted and blotted with paper towels. They were then rinsed with 1 mL of Washing Solution, blotted a second time and removed from the magnetic rack. A color solution, 500 μL of hydrogen peroxide and 3,3',5,5'-tetramethylbenzidine, was added, vortexed for two seconds, and allowed to incubate for 20 minutes. Finally, the color was fixed by adding 500 μL of 0.5% sulfuric acid, and the percentage absorbance was read at 450 nm on a photometer [29].

Water Quantity Data

Precipitation data was gathered from two different sources. The Army Corps of Engineers-Fort Worth District Internet site contained data on daily precipitation at Lake Lewisville [30]. Average precipitation data for Northeast Texas were obtained from a University of Texas Internet site [31]. The ACE's site also included calculated values for the total water volume flowing into the three lakes.

GIS Data and Analysis

<u>Geographical Position of Sampling Stations</u>

In order to conduct the spatial analysis portion of the study, a computer-based coverage of the sampling stations was required. This was performed with a GeoExplorer

3 Geographical Position System (GPS) receiver from Trimble Navigation Limited (Model 39100-00-ENG). Stations were visited during one of the sampling dates and the locations of each were gathered with the receiver. The GPS Pathfinder software, also by Trimble Navigation Limited, was used to transfer data from the GPS receiver to one of the computers in the lab. These points were then converted into an ArcView shape file using the Export utility of the Pathfinder software, and later opened as a theme in ArcView.

The GeoExplorer 3 receiver is only accurate to 100 feet unless data points are differentially corrected with data available from GPS base stations that supply real-time or post-processing information to precisely identify the location of each position. Unfortunately, the GPS base station for North Central Texas, located in Arlington, was not operational at the time of the GPS sampling. In order to correctly place each point on its location in the watershed, ArcView road and river coverages—provided by Mr. Bruce Hunter of the University of North Texas—were used to visually identify the sampling sites on the computer monitor and move the data points accordingly. Even though this procedure was not as accurate as it could have been if the points had been differentially corrected, it was deemed sufficient when considering the large scale of the watershed.

<u>BASINS Data and Functions</u>

The environmental analysis system BASINS—Better Assessment Science Integrating Point and Nonpoint Sources—was developed by the U.S. EPA "to facilitate examination of environmental information, to support analysis of environmental systems, and to provide a framework for examining management alternatives [32]." It is a combination of software and an environmental database designed to run from the ArcView interface and can be ordered from the U.S. EPA or downloaded from their web site at www.epa.gov/ost/basins. Included in the database are Digital Elevation Models (DEMs), STATSGO soils, rivers and roads coverages, land-use information, and many other types of data. Furthermore, BASINS includes different functions—the more important ones for this project being a watershed delineation tool and the Nonpoint Source Model (NPSM) which calculates runoff according to soil, land-use, and precipitation data.

The watershed delineation tool was very easy to use and effective. It was used to divide the Elm Fork Watershed into sub-watersheds, each representing one sampling station. This was accomplished by making the DEM, rivers, and stations themes visible in ArcView. The watershed delineation tool button was selected and the mouse was used to draw the area upstream of the sampling station that flowed into each of the river segments. The rivers and DEM coverages were used as backdrops to facilitate this procedure by providing a reference to the location of the streams and points of highest elevation in the watershed.

Land-Use Data

An integral part of this project was to determine how Atrazine concentrations relate to land-use and which areas of the watershed have the biggest potential for contributing Atrazine into the lakes. Three different land-use data sets were obtained for this purpose. The first one, developed for the Texas GAP project, was acquired from Texas Tech University. Fifty-two Landsat images from 1993 were used to classify all

Texas counties into over 60 land-use categories at a resolution of 90 meters per cell [33,34]. Many of these categories were different types of forests and grasslands, so, for this project, the data was grouped into six classes—see Table 2. The classification scheme used for the GAP project, as well as the recoding done for this project can be seen in Table 12 in the Appendix. Figure 13, also in the Appendix, illustrates the data.

Table 2- Atrazine Risk of Each Cover Type

Cover Type	Atrazine Risk	Classification
Water	NO	0
Barren	MEDIUM	2
Cropland	HIGH	4
Rangeland/Shrubland	LOW	1
Forest	NO	0
Urban	MEDIUM	2

A second data set was developed by the University of North Texas for the Cross Timbers Habitat Change Project sponsored by the Texas Parks and Wildlife- Brownwood Office. Four Landsat MSS images from August and September 1992 were classified using the scheme found in Table 13 in the Appendix. The data, illustrated in Figure 14 in the Appendix, have a resolution of 90-meter.

The third data set was obtained from the BASINS environmental analysis system. The BASINS data were older and less accurate than the other two, so they were used only for comparison. They were derived from 1:250,000-scale quadrangles of land-use/land-cover GIRAS spatial data of the conterminous United States, which were developed between 1977 and the early 1980s. The classification scheme and illustration for these data can be seen in Table 14 and Figure 15 in the Appendix.

Each of the data sets was grouped into the six classes shown in Table 2 and imported into ArcView. A summary of the quantity and percentage of each class in each sub-watershed was then developed for all the data sets.

HEC-PrePro and HEC-HMS

The concentration of Atrazine in each of the streams, by itself, is not indicative of how much Atrazine is entering a reservoir. For example, in the study conducted by Pope et al. [28], Atrazine concentrations in 1993 were much lower than those of 1994. However, 1993 was the year of the Midwest floods and the amount of water flowing in the rivers was much higher than in 1994, which, in turn, was dryer than normal. Even though the concentrations were lower, due to dilution, the total amount of Atrazine was greater since the rains and the floods washed more of the fields.

From preliminary data, it appeared that concentrations in some creeks were habitually higher than others. However, field observations showed that most of these creeks were of very low flow. Therefore, their contributions to the total Atrazine concentration of the reservoirs might be the same or lower than that of higher order, lower concentration streams.

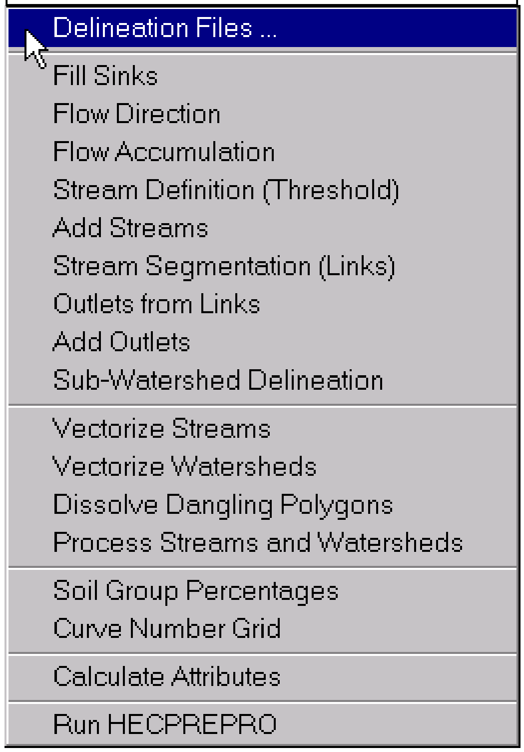
In order to estimate how much Atrazine is contributed by each stream and how much total Atrazine enters the reservoirs, both concentration and water flow need to be known. The first attempt was to gather flow data from available USGS gauge stations. However, most creeks did not have gauge stations, and those that did either lacked data for past sampling periods or water levels were so low that flow was not measurable. In light of this, an attempt was made to estimate water flow as runoff from rain events. In theory, since all creeks in the area are intermittent, rain-fed creeks, all flow can be attributed to runoff.

Originally, runoff was going to be predicted using BASINS' Nonpoint Source Model. However, NPSM was not useful for this study because some very important data needed for its calculations were outdated—i.e. Lake Ray Roberts, a new lake, did not appear in any of the water data and, therefore, it greatly affected the results. Instead, the programs HEC-PrePro and HEC-HMS, which also estimate runoff, were used.

HEC-HMS (Hydrologic Engineering Center- Hydrologic Modeling System) was developed by the Army Corps of Engineers and uses different precipitation models to estimate how much runoff occurs from any given rain event. Both real and theoretical rainfall data can be used, as well as different precipitation patterns. HEC-PrePro, short for pre-processing, was developed by the University of Texas' Department of Civil Engineering to provide the input requirements for the HEC-HMS model.

> It is a system of ArcView scripts and associated controls [that] has been developed to extract hydrologic, topographic, and topologic information from digital spatial data of a hydrologic system, and to prepare an input file for the Hydrologic Modeling System (HMS) developed by the Hydrologic Engineering Center (HEC) of the United States Army Corps of Engineers. Starting from the DEM and a SCS curve number grid, HEC-PrePro v. 2.0 delineates streams and watersheds, calculates parameters for each of them, determines their interconnectivity, and prepares an input file for HMS that includes the computed hydrologic parameters [35].

Figure 3- HEC-PrePro Menu [36]

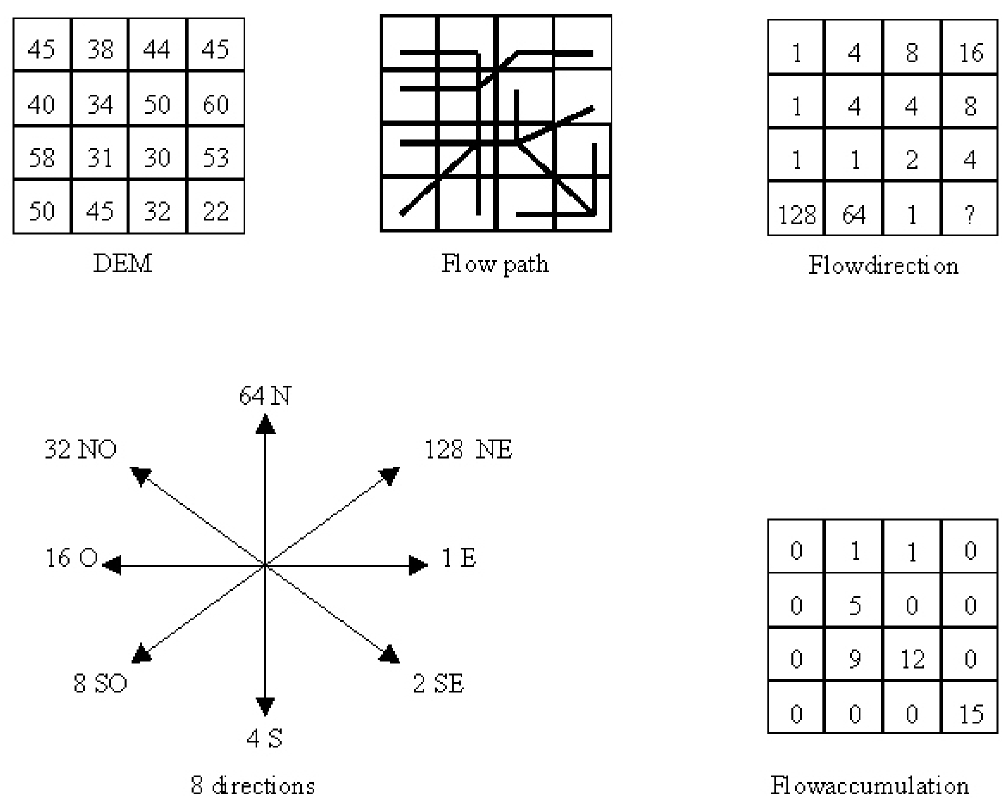


The steps for running HEC-PrePro were followed as instructed by Ahrens et al. for the GIS in Water Resources class at the University of Texas-Austin [36]. Figure 3 shows a menu from the ArcView interface detailing the steps involved—the step highlighted by the mouse pointer was skipped since it did not apply to these data.

The sole input requirement for HEC-PrePro's initial calculations is a Digital Elevation Model. DEM data from the USGS was incomplete; therefore, data from the BASINS database were used for this purpose. Since there were actually two Digital Elevation Models—one for the Elm Fork Watershed and one for the Denton Creek Watershed—they were joined using the "Union" command in Arc/Info in order to facilitate the processing in HEC-PrePro.

As shown in Figure 3, the first step involved filling in sinks. This process takes care of “aberrations [that] occur in the DEM which cause pits to form in the terrain” [36]. The next steps, Flow Direction and Flow Accumulation, are illustrated in Figure 4. The purpose of these steps is to compare each DEM cell with its neighbors and to determine which way water flows and where streams will be created.

Figure 4- Flow Direction and Flow Accumulation in HEC-PrePro [34]



Stream Definition (Threshold) allows the user to set the size of the area (in pixels) needed to accumulate into any given pixel before it became a stream. The greater number of pixels, the fewer the streams, and the faster the computations would be. For these data, a threshold of 100 cells was chosen, which meant that each stream pixel would drain about 25 km^2, since the DEM cells were about ½ km on each side. If stream segments were not created where necessary due to a high threshold, they could be added manually with the Add Stream command. However, since all the streams needed for this study were created correctly, that step was skipped.

Once the streams had been defined, the Stream Segmentation command grouped stream pixels located within the same two junctions into one segment and gave each of these segments a unique identification number. The next step, Outlet from Links, identified the most downstream cell of each segment as a potential watershed outlet. If a desired outlet was not produced from the prior step, it could be added manually with the Add Outlets step. Finally, the last command of the initial portion of the menu, Sub-Watershed Delineation, delineated all the sub-basins that were represented by each of the stream segments.

The next section of the menu involved basic data manipulation. The steps Vectorize Streams and Vectorize Watersheds converted the previously created stream and watershed coverages from raster to vector format. Dissolve Dangling Polygons removed small areas of land that became separated from larger sections during the raster to vector conversion. Once the streams and sub-watersheds coverages had been cleaned up, the Process Streams and Watersheds step established the connectivity of the sub-watersheds.

The amount of water runoff following a rain event is not only a function of the precipitation, but also of the type of soil present—which affects how well water is absorbed—and how the land at any point of the watershed is used—which determines the quantity and quality of the soil. The next two steps in HEC-PrePro, Soil Group Percentages and Curve Number Grid, addressed these factors.

The Soil Group Percentages option gathered information about the soils of the study area and created a table with these data for further use. The information for this step was downloaded from a University of Texas FTP site [37]. The first file downloaded, “mapunit.dbf”, included a listing of the STATSGO map units for the state of Texas. A second file, “comp.dbf”, contained soil data for these map units. Among these, the more important data were the soils found in each map unit, what percentage of the map unit was comprised by each soil type, and which Hydrologic Soil Group these soils belonged to—A, B, C, or D depending on the soil texture. The Soil Groups Percentages step created a table called “muidjoin.dbf,” which listed the map units, and the percentage of A, B, C, and D soils and water in each map unit.

The next step, Curve Number Grid, performed several functions. It began by joining the table with the land-use information to a look-up table, “lookup.dbf”, which was also downloaded from the University of Texas FTP site. This table listed the Anderson land-use codes and four different percentages of water runoff associated with each Hydrologic Soil Group. The tables were linked according to the land-use code field that was common to both. It then joined the Soil Group Percentages table to the one containing the attributes of the soil coverage. The end results of these first two functions were two tables—one with land-use data and how much runoff would be attributed to each land-use type and the other with soil data with the associated runoff.

It then proceeded to create nine grid coverages—four grids with the different percentages of each soil type found in the study area ($Soil_{A-D}$), four grids for the percentages of runoff from each land-use type if each was found in any one of the four soils (LU_{A-D}), and one grid that represented those areas in the watershed that were covered by water (Water). The next step was supposed to perform computations with these nine grids and produce an output grid representing the percentage of runoff that would result at any point in the watershed. However, this part of the program always resulted in zero values, meaning that there would be no runoff. By looking at the script of the program, it was determined that the algorithm provided by the authors was not correct, so a script that executed the following algorithm was created:

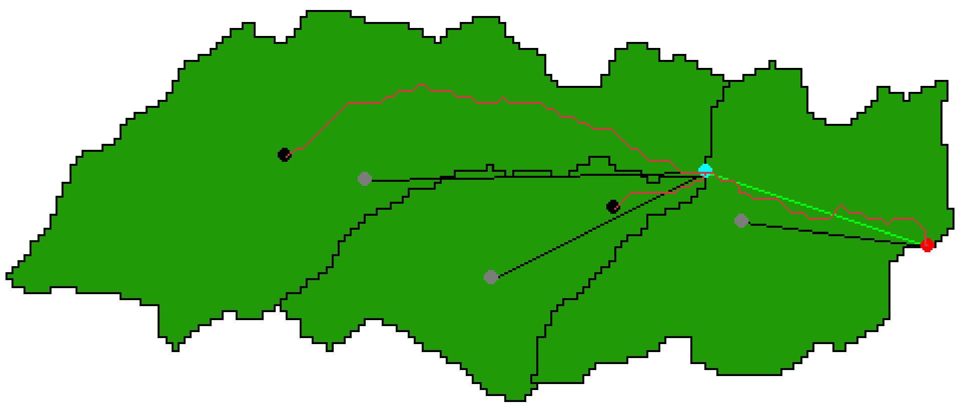
Equation 1—Percent Imperviousness

$$\frac{(SoilA*LUA) + (SoilB*LUB) + (SoilC*LUC) + (SoilD*LUD) + (Water*100)}{SoilA + SoilB + SoilC + SoilD + Water}$$

This equation compensated for different runoff results from the same land-use over various soils. For example, if there were 80% Type A soils and 20% Type B and no water was present, the percent runoff associated with that particular land-use if found on soil A would be multiplied by 80, if found on soil B by 20, added together, and divided by 100. The result would be a value of the percent runoff for each individual pixel.

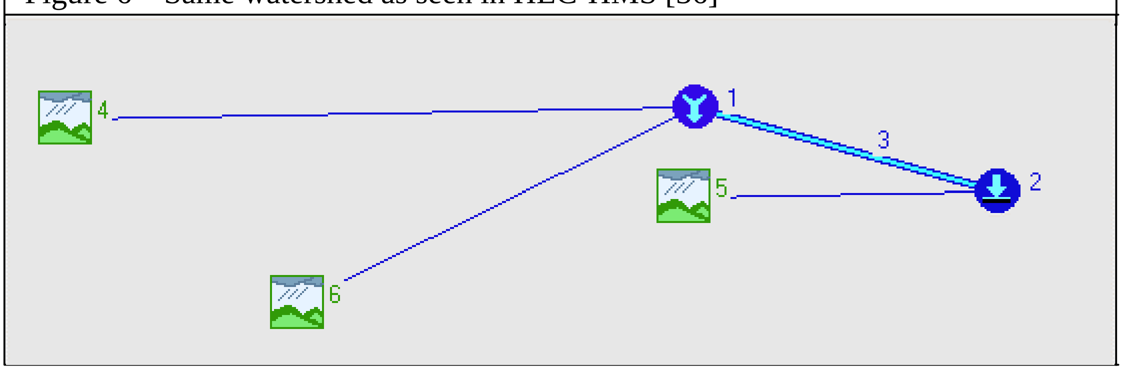
During the next step, Calculate Attributes, the program calculated hydrologic parameters for the streams and watersheds. This section allows the user to select which portion of the study area will be processed by the final step. Since many small watersheds were created in a previous step, all those watersheds that made up each of the sub-watersheds for the individual sampling stations were selected. This step was repeated 22 times to encompass every sampling site in the Elm Fork Watershed.

Figure 5—Example watershed as seen in ArcView [33].



The final step, Run HEC-PrePro, takes each sub-watershed and creates an input file for the HEC-HMS. Figures 5 and 6, taken from Ahrens et al., show a sample watershed as seen in ArcView and HEC-HMS respectively [36]. Each square in Figure 6 contains information on the runoff percentage and size of each basin, the circles represent river junctions or watershed outlets, and the lines represent streams and accumulation channels.

Figure 6—Same watershed as seen in HEC-HMS [36]



The steps for the HEC-HMS portion of the analysis were followed as instructed by Maidment and Ahrens to their Surface Water Hydrology class at the University of Texas-Austin [38]. HEC-HMS is comprised of three elements—the basin model, the precipitation model, and the control specifications. The basin models were developed previously with HEC-PrePro and imported into the HEC-HMS project module. The precipitation model contains information on the strength of the rain event—for this study, a two-year storm event was assumed. The data gathered from the University of Texas-Austin Internet site was used to create the precipitation model. The control specifications state how long the storm event lasts. A 24-hour time frame was chosen for the precipitation because most rainstorms in Northeast Texas are short and intense. The output listed the amount of water passing through each of the portions of the watershed until reaching the outlet points, which were also the sampling sites. In order to try to eliminate any biases created by both HEC-PrePro and HEC-HMS, the runoff values for each of the sub-watersheds were added together and divided by the total amount to provide the percentage of water contributed by each to the entire watershed.

<u>Atrazine Loads</u>

The amount of Atrazine entering a reservoir depends on the concentrations found in the creeks that feed the reservoir and their flow rate. By using the inflow data for the three lakes and the percentage flowing from each sub-watershed as estimated by the HEC-HMS model, the flow rate of each of the creeks was estimated. The Atrazine load was then estimated by multiplying the flow of each creek by the mean and median concentrations. The values of the creeks that flow into the same lake were added together to obtain the total Atrazine load per day for each lake.

Statistical Analysis

Correlations of Atrazine Concentrations between Sampling Stations

The first null hypothesis stated that there would be no difference in atrazine concentrations among the different sampling sites. To evaluate this hypothesis, a one-way analysis of variance was performed using the statistical software S-Plus. This was repeated for the natural log and $\log_{10}$ of the concentrations. Additionally, a Kruskal-Wallis rank sum test was conducted on the concentrations, as well as the natural log and $\log_{10}$ values.

Relationships between Atrazine Concentration and Land-Use

To test the second hypothesis, the sub-watershed coverage was overlaid on all three land-use coverages and the pixels of each of the six cover types (see Table 2) were counted using ArcView and converted into square kilometers. Correlation analyses and linear regressions were computed on the quantity of each land-use cover type and Atrazine concentrations for all sampling periods using S-Plus. This was done for all land-use data sets. Correlations and linear regressions were also computed between the percentages of each land-use type and the concentrations found for all data sets. Furthermore, the previous steps were repeated using the natural log and the $\log_{10}$ of the concentrations.

Relationships between Atrazine Concentration and Precipitation

Since Atrazine enters river systems as runoff due to precipitation, the third hypothesis implied that Atrazine concentrations would be higher following periods of more intense rain. To test this hypothesis, the daily rain data for Lake Lewisville was used to calculate the cumulative rainfall for the previous 3, 10, 15, 30, 60, 90, 120, and 360 days before each sampling date. Linear regressions were conducted between the results of the 3, 10, and 15 day rain amounts and the Atrazine concentrations at all sites. This was also performed on the natural log and $\log_{10}$ of the concentrations. Finally, the concentrations at Lake Lewisville, Lake Ray Roberts, and Lake Grapevine were correlated with precipitation for the previous 30, 60, 90, 120, and 360 days.

RESULTS

Water Quality

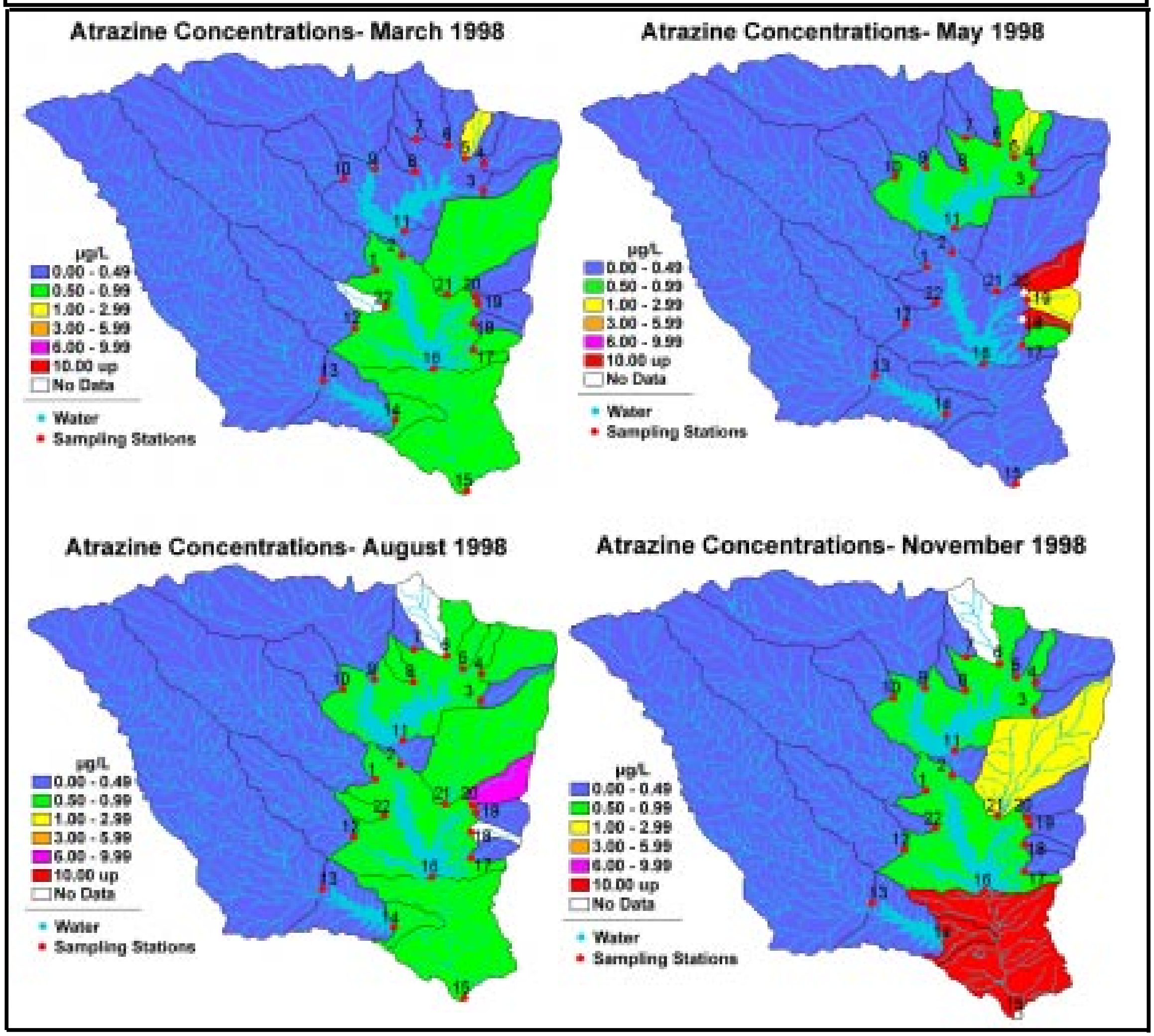
Table 3- Atrazine concentrations

ID	Pos.	Mar 98	May 98	Aug 98	Nov 98	Feb 99	May 99	Aug 99	Dec 99
1	W	<0.1	<0.1	<0.1	<0.1	0.10	0.10	<0.1	<0.1
2	E	0.37	0.44	0.41	0.42	0.65	0.26	0.35	0.08
3	NE	<0.1	0.11	0.43	0.13	1.35	7.55	0.80	<0.1
4	NE	0.36	<0.1	0.74	0.35	6.72	4.76	0.38	<0.1
5	NE	2.00	1.10	0.69	0.27	11.53	7.11	1.20	<0.1
6	NE	<0.1	<0.1	ND	ND	<0.1	<0.1	0.38	<0.1
7	NE	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
8	NE	0.13	0.46	0.73	0.31	0.76	0.20	0.22	<0.1
9	N	0.12	<0.1	0.13	<0.1	<0.1	<0.1	0.15	<0.1
10	NW	<0.1	0.27	<0.1	<0.1	<0.1	1.65	<0.1	<0.1
11	NE	0.43	0.70	0.78	0.61	1.28	0.44	0.38	<0.1
12	W	<0.1	0.18	0.10	<0.1	0.12	3.83	<0.1	<0.1
13	W	<0.1	<0.1	<0.1	<0.1	0.37	1.57	<0.1	<0.1
14	W	0.32	0.19	0.27	0.24	0.44	0.22	0.28	<0.1
15	S	0.74	0.23	0.57	15.61	0.38	0.61	0.70	0.13
16	E	0.93	0.49	0.73	0.61	0.56	0.55	0.64	<0.1
17	E	0.75	0.72	0.15	0.15	0.43	0.31	0.16	0.12
18	E	<0.1	11.72	ND	<0.1	<0.1	6.80	0.41	0.12
19	E	<0.1	1.31	0.38	<0.1	<0.1	3.24	0.30	<0.1
20	E	0.17	16.09	6.94	0.13	0.23	4.15	<0.1	<0.1
21	E	0.63	0.49	0.67	1.89	0.41	3.10	0.70	12.74
22	W	ND	0.39	0.65	0.46	0.46	0.49	0.96	0.36
23	W	0.25	0.57	0.69	0.57	0.58	0.70	0.58	0.14
24	E	0.29	0.53	0.62	0.46	0.44	0.48	0.28	0.11
25	E	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.26	<0.1
26	W	0.17	0.15	0.29	0.31	0.16	0.26	0.28	<0.1
27	NA	ND	0.95	1.27	0.88	0.64	0.58	0.62	0.20

Overall, Atrazine concentrations around the area were fairly low. The vast majority of values were below 1.0 µg/L, but a few reached levels as high as 16.1 µg/L.

Table 3 lists the concentration results for all stations for all sampling dates. These are shown graphically in Figures 7 and 8.

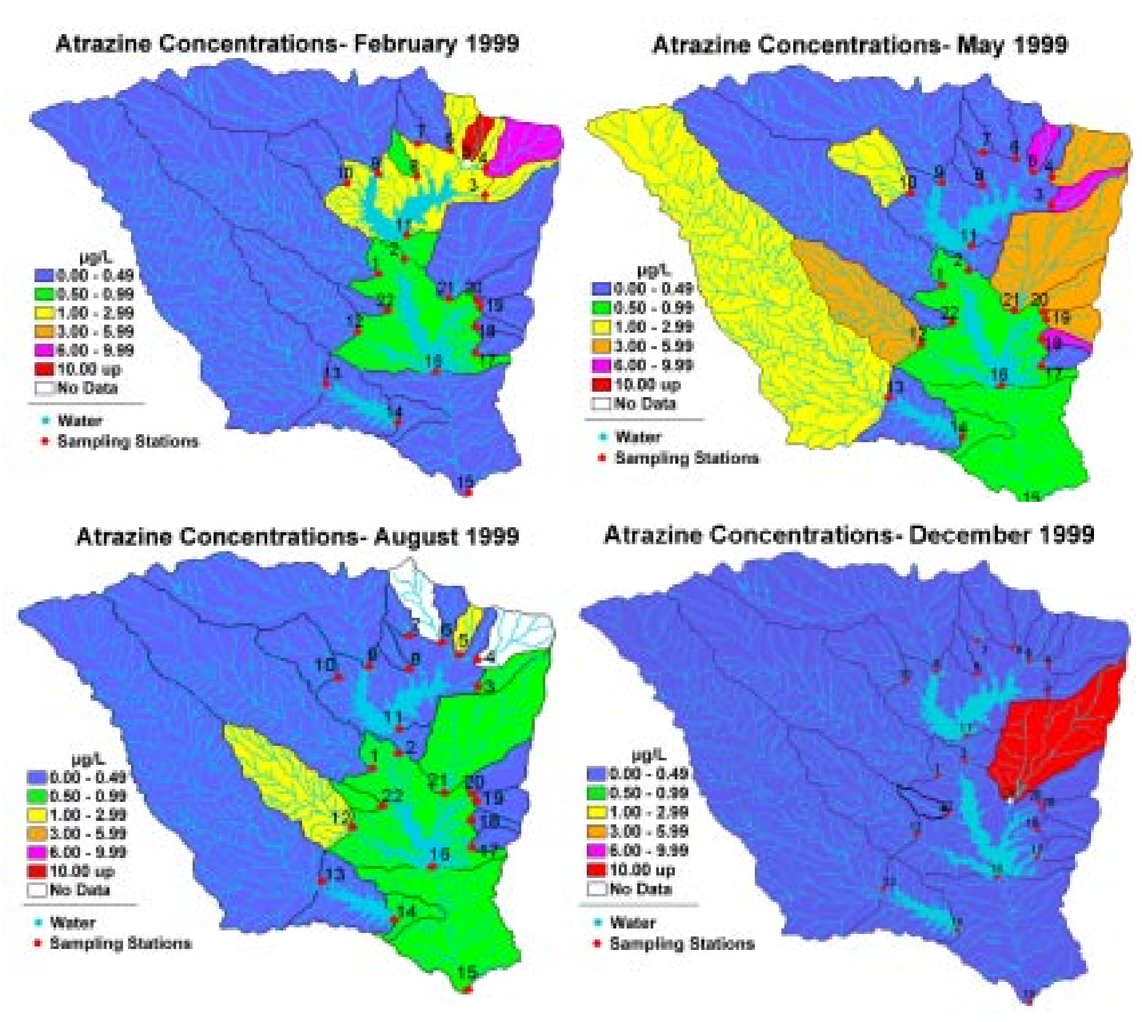
Figure 7—Atrazine concentration in 1998



Except for the missing data for the March 1998 collection date, for which sampling was not conducted, all other missing values were attributed to dry streams. The column "Pos" in Table 3 indicates the position of the sampling site in the study area. Of the 27 sampling sites, nine of them were found to have concentrations greater than 3 µg/L and five, Range Creek, Spring Creek, Cottonwood Branch, Doe Branch, and Little Elm

Creek exceeded the EPA Maximum Contaminant Level more than once. As seen in Figures 7 and 8, all five of these streams are located in the eastern side of the watershed, and three of the other four streams that exceeded the MCL only once are also on the east side.

Figure 8—Atrazine concentration in 1999



All drinking water samples were below 3 µg/L, but only Station 25—the Upper Trinity Regional Water District Plant, which uses activated carbon in its purification process—met the European standards of 0.1 µg/L at any time. Furthermore, five of the sampling stations—Stations 5, 15, 18, 20, and 21—failed to meet the 3 μg/L four-quarter average set by the EPA at least once. Three of these violations took place in 1998 and two in 1999.

GIS Data and Analysis

Geographical Position of Sampling Stations

Figures 7 and 8 display the location of the sampling stations as red dots. Each dot represents the most downstream point of the streams and their tributaries in their individual sub-watersheds. Table 4 lists the coordinates of each site.

Table 4- Sampling Locations

ID	Longitude	Latitude	ID	Longitude	Latitude
1	97 05 48.27 W	33 16 28.30 N	13	97 12 31.96 W	33 02 25.42 N
2	97 02 31.59 W	33 18 19.06 N	14	97 03 26.41 W	32 57 28.35 N
3	96 52 12.89 W	33 26 31.72 N	15	96 54 22.88 W	32 48 28.05 N
4	96 52 10.99 W	33 29 57.94 N	16	96 58 29.69 W	33 04 01.04 N
5	96 54 30.38 W	33 30 34.22 N	17	96 53 29.07 W	33 06 24.05 N
6	96 56 34.50 W	33 32 17.34 N	18	96 53 29.27 W	33 09 44.21 N
7	97 00 48.51 W	33 33 06.38 N	19	96 52 80.25 W	33 12 13.63 N
8	97 00 53.09 W	33 28 57.99 N	20	96 53 20.16 W	33 13 08.72 N
9	97 05 55.59 W	33 29 17.84 N	21	96 56 48.51 W	33 13 19.46 N
10	97 09 49.28 W	33 28 03.00 N	22	97 04 35.07 W	33 11 44.10 N
11	97 02 14.06 W	33 21 25.80 N	27	95 36 38.79 W	33 18 43.75 N
12	97 08 29.46 W	33 09 06.54 N			

Watershed Delineation with BASINS

Figures 7 and 8 also show the results of the sub-watershed delineation. The black lines are the boundaries of each sub-watershed in which any drop of water will flow toward its corresponding sampling site at the downstream end. The distinct difference in sub-watershed size between the east and west sides of the watershed, smaller and more numerous in the east while larger and fewer in the west, depicts the contrast in terrain from rolling hills to flat plains.

Land-Use Analysis

Land-use data were gathered only for the study area around the Elm Fork watershed. Tables 5 shows the area made up by each of the land-use classes for each of the sub-watersheds for the GAP data. Some discrepancy existed between the three different data sources. Differences could be attributed to different techniques used for the

Table 5- Land-Use by Sub-watershed (in sq. km)- from GAP data

ID	Water	Urban	Agriculture	Forest	Grassland	Barren	Total Area
1	3.86	12.86	231.92	406.18	230.20	0.64	885.67
2	0.43	1.07	12.22	16.50	20.58	0.00	50.80
3	0.00	0.86	12.00	17.36	25.08	0.00	55.30
4	0.00	1.50	22.08	39.87	65.59	0.00	129.03
5	0.00	1.07	6.00	8.57	23.58	0.00	39.22
6	0.21	0.86	39.65	51.44	14.15	0.00	106.31
7	1.71	1.71	15.65	20.36	3.64	0.00	43.08
8	0.00	0.21	13.72	14.36	2.57	0.00	30.87
9	2.57	21.86	142.75	306.30	187.76	0.00	661.25
10	0.00	1.29	44.37	61.09	42.65	0.00	149.40
11	107.17	10.93	132.46	175.33	132.25	0.00	558.15
12	1.07	11.15	115.10	119.17	76.95	0.00	323.44
13	8.36	19.72	493.63	639.82	417.97	5.14	1584.64
14	28.08	21.65	48.44	71.81	35.58	0.00	205.56
15	10.93	219.70	88.10	143.40	113.60	0.00	575.73
16	109.32	53.80	139.97	177.69	96.45	0.00	577.23
17	0.21	6.64	15.00	10.29	6.86	0.00	39.01
18	0.00	4.72	12.43	4.93	7.72	0.00	29.79
19	0.00	0.86	25.29	22.51	14.36	0.00	63.02
20	0.00	3.22	36.44	25.29	17.58	0.00	82.52
21	2.79	10.72	107.60	103.53	192.69	0.00	417.33
22	0.00	21.86	3.64	9.22	1.07	0.00	35.80
Total	276.72	428.26	1758.47	2445.02	1728.89	5.79	6643.15

analysis of different source data by different analysts. However, all three data sets agreed that the watershed is made up mostly of agriculture, forest, and grassland as exemplified above by Table 5.

<u>Flow Contributed by Sub-watersheds</u>

Table 6- Flow from Sub-watersheds in Lake Lewisville

ID	% Inflow	TMF (cfs)	cfs/stream	million L/day
1	25.23	228	57.52	140.72
2	2.01	228	4.58	11.21
12	21.22	228	48.38	118.37
17	5.01	228	11.42	27.93
18	3.14	228	7.16	17.52
19	7.35	228	16.76	41.00
20	6.13	228	13.98	34.21
21	26.84	228	61.19	149.70
22	3.07	228	7.01	17.14

Table 7- Flow from Sub-watersheds in Lake Ray Roberts

ID	% Inflow	TMF (cfs)	cfs/stream	million L/day
3	8.89	117	10.40	25.44
4	15.34	117	17.95	43.91
5	4.38	117	5.13	12.55
6	6.56	117	7.67	18.77
7	3.21	117	3.75	9.18
8	2.79	117	3.26	7.98
9	42.37	117	49.58	121.29
10	16.46	117	19.26	47.11

Table 8- Flow from Sub-watersheds in Lake Grapevine

ID	% Inflow	TMF (cfs)	cfs/stream	million L/day
13	100	38.5	38.5	94.19

The output of the HEC-HMS model was an estimate of how much water would flow from any given sub-watershed under a predetermined condition. The outputs of each sub-watershed for each of the reservoirs were added together and the percentage contributed by each sub-watershed calculated. Tables 6 through 8 show the inflow percentage attributed to each sub-watershed, as well as the total median flow (TMF) into the reservoirs provided by the USACE and the estimated flow from each of the sub-watersheds based on these factors.

<u>Atrazine Loads</u>

Figure 9—Mean and Median Atrazine Concentrations

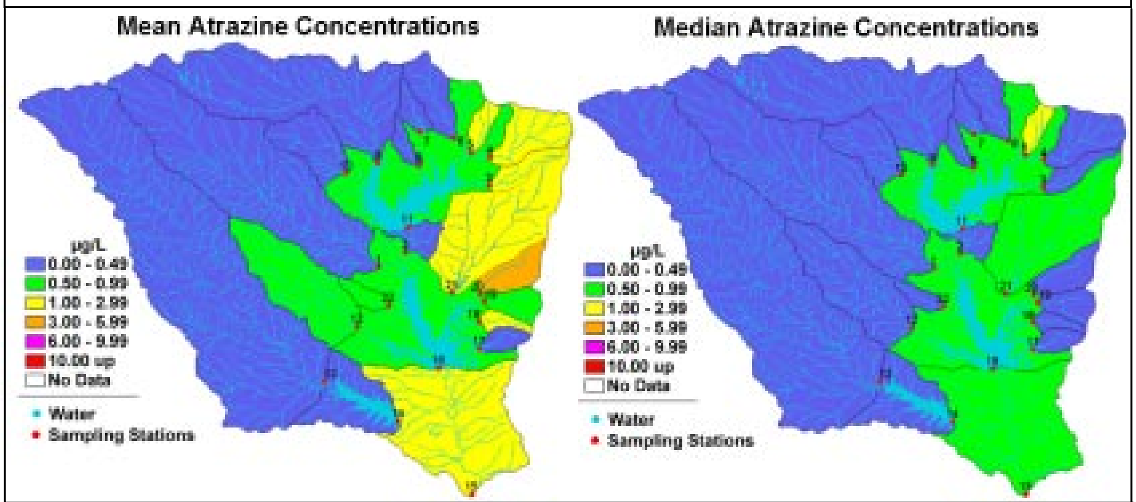


Table 9- Atrazine Loading of Lake Lewisville per Day				
ID	[Mean] (µg/L)	[Median] (µg/L)	Mean(g)	Median(g)
1	0.04	0.03	5.80	3.52
2	0.37	0.39	4.15	4.33
12	0.55	0.09	64.90	11.13
17	0.35	0.24	9.79	6.61
18	2.75	0.12	48.23	2.11
19	0.68	0.19	27.73	7.71
20	3.47	0.20	118.77	6.77
21	2.58	0.68	386.16	102.47
22	0.54	0.46	9.21	7.95
		Total	674.75	152.60

The mean and median concentrations for each of the sub-watersheds were multiplied by the stream flow to estimate the Atrazine loading into each of the three lakes—assuming that either the mean or median concentrations were present at all times.

As expected, mean loadings were higher due to the few excessive concentrations found at a handful of sites. Figure 9 illustrates the mean and median concentrations by sub-watershed and tables 9 through 11 list loadings for each of the reservoirs.

Table 10- Atrazine Loading of Lake Ray Roberts per Day				
ID	[Mean] (µg/L)	[Median] (µg/L)	Mean (g)	Median (g)
3	1.30	0.28	33.16	7.09
4	1.68	0.37	73.55	16.14
5	2.99	1.15	37.49	14.41
6	0.08	0.03	1.53	0.56
7	0.01	0.00	0.12	0.01
8	0.35	0.26	2.79	2.09
9	0.07	0.07	8.93	8.98
10	0.26	0.04	12.30	1.72
		Total	169.87	51.00

Table 11- Atrazine Loading of Lake Grapevine per Day				
ID	[Mean] (µg/L)	[Median] (µg/L)	Mean (g)	Median (g)
13	0.28	0.06	26.14	5.75

The total mean loadings per day were 26.14, 169.87, and 674.75 grams for Lake Grapevine, Lake Ray Roberts, and Lake Lewisville, while the total median loadings were 5.75, 51.00, and 152.60 grams. When taking into account the different flow rates into the three reservoirs, Lake Lewisville also had the highest loads per volume at 2.96 mean and 0.67 median g/cfs, followed by Lake Ray Roberts with 1.45 mean and 0.44 median g/cfs, while Lake Grapevine was lowest at 0.68 mean and 0.15 median g/cfs.

An increase in the total Atrazine loading per day for all three reservoirs was detected between 1998 to 1999. While total mean loadings in 1998 were 4.94, 49.91, and 462.77 grams per day for Lake Grapevine, Lake Ray Roberts, and Lake Lewisville, 1999 mean loadings were 47.34, 289.36, and 891.80 grams per day. Total median loadings also increased from 4.71, 42.87, and 264.28 grams per day in 1998 to 20.72, 206.07, and 343.29 grams per day in 1999.

Effects of Lake Chapman

An additional 173.65 mean and 150.91 median grams per day will enter Lake Lewisville when the water pipeline from Lake Chapman is completed and 62.59 million gallons of water per day are pumped into the reservoir.

Statistical Analysis

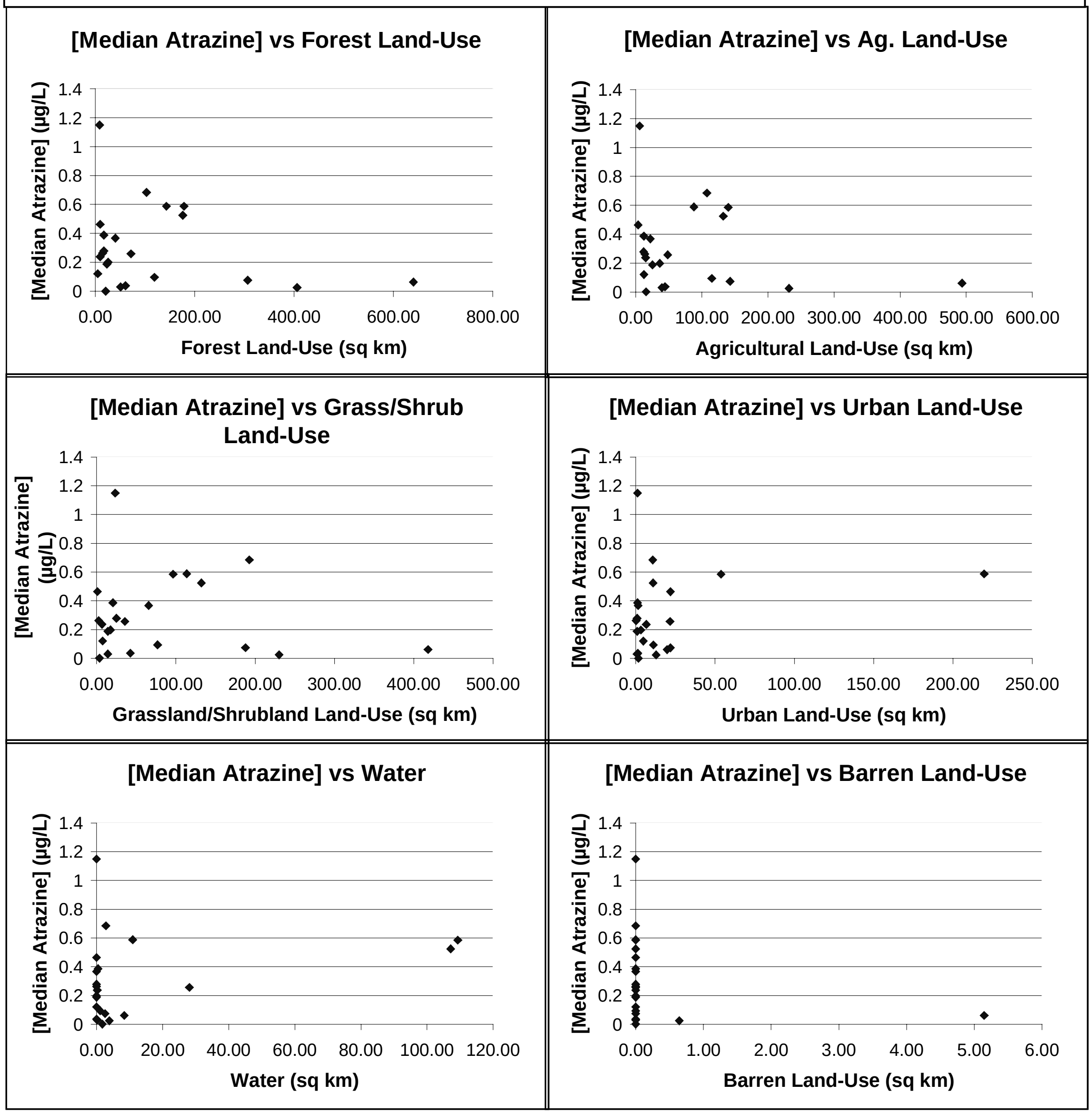
Correlations of Atrazine Concentrations between Sampling Stations

The ANOVA results showed that there was a statistically significant difference in concentration between the sampling stations with a probability of 0.034. Likewise, the ANOVAs performed on the $\log_{10}$ and natural log of the concentrations showed a highly significant difference between the stations with a probability of 1.25×10^{-9}. The Kruskal-Wallis Rank Sum test also showed highly significant difference for all three data sets—$\log_{10}$, natural log, and the original concentrations.

Relationships between Atrazine Concentration and Land-Use

Correlation analysis between Atrazine concentrations and land-use analysis indicated that there was no relationship between land-use and the concentrations found at the various sites. This was also the case for the mean and median concentrations as well as the log-transformed values. Figure 10 is a sample scatter plot of the median concentrations versus the various land-uses. As the figure shows, no obvious trend is present.

Figure 10- Plots of Atrazine concentrations and various land-uses



<u>Relationships between Atrazine Concentration and Precipitation</u>

Similarly, there was no correlation between Atrazine concentrations and prior precipitation. This was true for concentrations in streams and short-term precipitation and for concentrations in lakes and long-term precipitation. Figure 11 is a sample plot of the Atrazine concentrations found at Little Elm Creek and the precipitation accumulated during the previous three and 10 days. Figure 12 is a sample plot of the concentrations found in Lake Lewisville and the accumulated precipitation during the previous 30 and 90 days. There was also no relationship between mean, median, and log-transformed values and precipitation.

Figure 11-Plots of stream sample Atrazine concentration and short-term precipitation

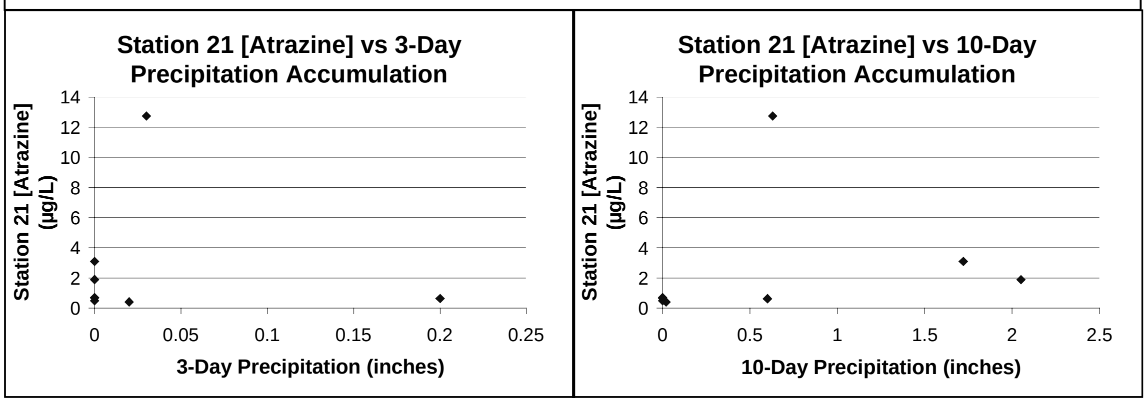
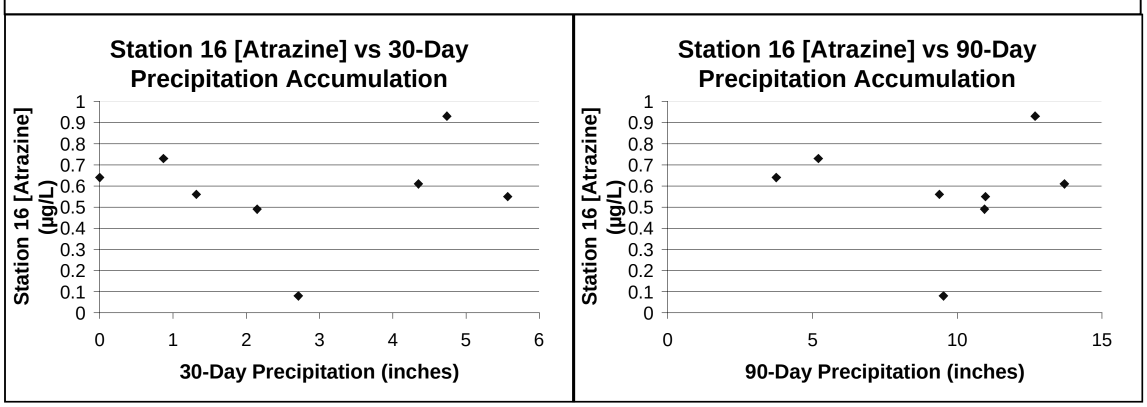


Figure 12-Plots of lake sample Atrazine concentration and long-term precipitation



DISCUSSION

Water Quality

The purpose of this study was to examine the water quality in the Elm Fork Watershed with respect to the herbicide Atrazine. Compared to the United States Environmental Protection Agency's Maximum Contaminant Level standards for drinking water, Atrazine concentrations, with a few exceptions, were fairly low. For the most part, levels were lower than the MCL of 3 µg/L. More importantly, all but one of the reservoir and drinking water samples were less than one third of this MCL, and the only exception was a reading of 1.2 µg/L. However, 69 percent of all readings, including reservoir and drinking water samples, exceeded the more stringent European standards of 0.1 µg/L [1,2]. This raises the questions of which of the two agencies has the more reasonable standard and whether the levels found in the Elm Fork Watershed are safe or dangerous.

As mentioned earlier in this paper, it was not the intention of this study to answer these questions, but to help determine where the Atrazine is coming from and how much is entering our drinking water supply. Thereby, if future research or popular opinion reduces the MCL, the areas in the watershed that most affect Atrazine concentrations can be spotted quickly and efforts to reduce use implemented.

As figures 7 through 9 illustrate, most Atrazine spikes appear in the eastern portion of the watershed. Even though this area is more agriculturally intensive than the western end, a significant relationship between concentrations and land-use was not found. This was mainly due to the fact that Atrazine is not used in all sorts of agricultural lands, so better land-use data are needed before ruling out the possibility for such a relationship.

Concentrations in streams by themselves are not the sole cause for higher levels in a reservoir. Water flow plays an important role in the determining the Atrazine concentration of a reservoir. As shown in Table 9, Station 12 had among the lowest concentrations detected, however, its large volume carried a larger load of Atrazine than many of the other sites, even those with much higher concentrations. Higher quantities are brought into the stable environment of the reservoir where chemical degradation is diminished and concentrations raised. Tables 9 through 11 show that, when taking both concentrations and stream volumes into account, the total loads into the reservoirs can be attributed to all sections of the watershed.

Nevertheless, there are a few sub-watersheds that generate greater concern than others and should be examined in more detail. Of greatest interest is Little Elm Creek, Station 21, which flows into Lake Lewisville from the east. The third highest concentration measured, 12.74 µg/L, was recorded in this stream on December 1999. Subsequent calculations showed that Little Elm Creek contributed the largest amounts of Atrazine—over three times greater than the next highest station's mean load and over six times greater than the next highest median load.

Other streams that require closer monitoring include Range Creek, Spring Creek, Cottonwood Branch, and Doe Branch. Not only did the concentrations observed in these streams exceed 3 µg/L on more than one occasion, but their locations in the study area also draw attention. Range Creek and Spring Creek are found in northeast corner of the watershed and both flow into Lake Ray Roberts. Both streams are adjacent to each other, which brings into question what activities take place in the area to induce elevated concentrations on both streams. Likewise, Cottonwood Branch and Doe Branch are located very near each other to the east side of Lake Lewisville and Doe Branch is adjacent to Little Elm Creek. Again, activities in this area are suspect and more detailed information should be gathered on where and how much Atrazine is being used.

Statistical Analysis

Statistically, it was only shown that concentrations at the different stations were significantly different from each other. However, neither a relationship between Atrazine concentrations and land-use, nor one between concentrations and precipitation, could be established. There are various possible explanations for these results. One explanation is that these two relationships do not exist in the Elm Fork Watershed. Another explanation is that the data gathered was not of sufficient quality and quantity to manifest such relationships. Therefore, until better data are obtained, these questions of relationship are better left unanswered.

Recommendations for Future Studies

The scope of this project was very broad. Many stations were sampled for a long period of time at long intervals. Future studies should take the following suggestions into consideration. Data for the first rain event following the application of the herbicide is critical for a better understanding of the quantity of Atrazine being washed off the fields with the runoff. Subsequent rain events should also be studied in order to determine how much additional Atrazine is entering the reservoirs and the rate of decrease from event to event. Water quality data should also be analyzed by GC-MS to ensure that the ELISA results are satisfactory. Further attention should also be invested in obtaining precipitation data from all areas of the watershed as well as stream flows from the individual streams. This would allow a better understanding of the effects of precipitation on concentrations and stream flows, and it would also make calculations of Atrazine loads more accurate.

Finally, better land-use data are needed to be able to establish a relationship between land-use and concentrations and loads. The data would need to be current and more detailed, as the areas around the metroplex are constantly changing. Atrazine is not applied to all agricultural areas; therefore corn, sod, sorghum, and any other predominant crops of the region should be classified so concentrations can be correlated to any particular use.

Conclusions

This study attempted to assess the water quality of the Elm Fork Watershed with regards to the herbicide Atrazine. Concentrations were, for the most part, lower than the Maximum Contaminant Level set by the USEPA. Statistically significant differences in concentrations were detected between the 27 sampling stations and areas of high concentrations were identified. However, correlations between Atrazine concentrations and land-use and precipitation were unsuccessful. Further analysis with more detailed data should be conducted before any relationships are discarded.

APPENDIX

Table 12- GAP Land-Use Classification Scheme and Recode		
Code	Description	Recode
1	Water	Water
2	Bare Soil	Barren
3	Cloud	No data
4	Cropland	Agricultural
5	Urban Area	Urban
6	Unknown	No data
7	Rounded-Crowned Needle-Leaved Evergreen Forest	Forest
8	Extremely Xeromorphic Deciduous Shrubland	Grass/Shrub
9	Microphyllous Evergreen Shrubland	Grass/Shrub
10	Lowland Mixed Evergreen - Drought Deciduous Shrubland	Grass/Shrub
11	Succulent Extremely Xeromorphic Evergreen Shrubland	Grass/Shrub
12	Facultatively Deciduous Xeromorphic Subdesert Shrubland	Grass/Shrub
13	Medium-Tall Bunch Temperate or Subpolar Grassland	Grass/Shrub
14	Temperate or Subpolar Grassland with a Sparse Shrub Layer	Grass/Shrub
17	Semipermanently Flooded or Subpolar Grassland	Grass/Shrub
18	Evergreen Extremely Xeromorphic Subdesert Shrubland	Grass/Shrub
19	Sclerophyllous Broad-Leaved Evergreen Shrubland	Grass/Shrub
20	Temporarily Flooded Cold-Deciduous Woodland	Forest
21	Short Sod Temperate or Subpolar Grassland	Grass/Shrub
22	Cold-Deciduous Woodland	Forest
24	Annual Graminoid or Forb Vegetation	Grass/Shrub
25	Wetland	Forest
28	Intermittently Flooded Temperate or Subpolar Grassland	Grass/Shrub
29	Round-Crowned Needle-Leaved Evergreen Woodland	Forest
33	Temperate Broad-Leaved Evergreen Woodland	Forest
34	Sand Flats	Barren
35	Consolidated Rock Sparse Vegetation	Barren
36	Temp. Flooded Grassland w/ Sparse Cold-Deciduous Trees	Grass/Shrub
37	Dunes with Sparse Herbaceous Vegetation	Barren
38	Tall Sod Temperate Grassland	Grass/Shrub
40	Temperate Broad-Leaved Evergreen Shrubland	Grass/Shrub
42	Temporarily Flooded Microphyllous Shrubland	Grass/Shrub
45	Low Tropical or Subtropical Perennial Forb Vegetation	Grass/Shrub
47	Broad-Leaved Evergreen - Cold-Deciduous Woodland	Forest
51	Lowland or Submontane Cold-Deciduous Forest	Forest
55	Planted/Cultivated Woodland	Forest
56	Medium-Tall Sod Temperate or Subpolar Grassland	Grass/Shrub
63	Temporarily Flooded Cold-Deciduous Forest	Forest

Figure 13—GAP Land-Use Data

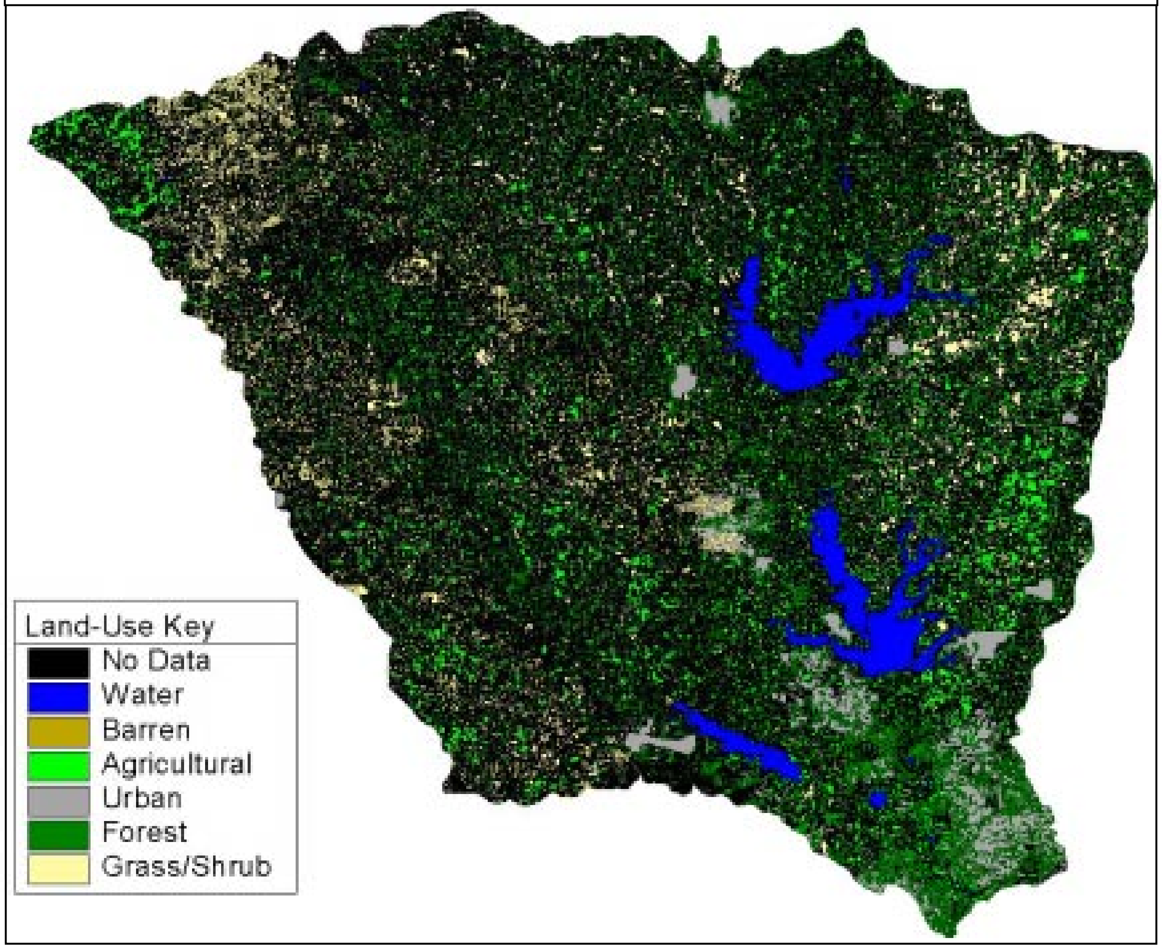


Table 13- UNT Land-Use Classification Scheme and Recode			
Code	Classification	Recode	Reclassified
1	Water	1	Water
2	Fallow	5	Forest
3	Forest	5	Forest
4	Forest/Shrubland	5	Forest
5	Shrub	6	Shrubland/Grassland
6	Pastureland	6	Shrubland/Grassland
7	Cropland	3	Agricultural
8	Bare	2	Barren
9	Shadow	-9999	No Data
10	Cloud	-9999	No Data

Figure 14—UNT Land-Use Data

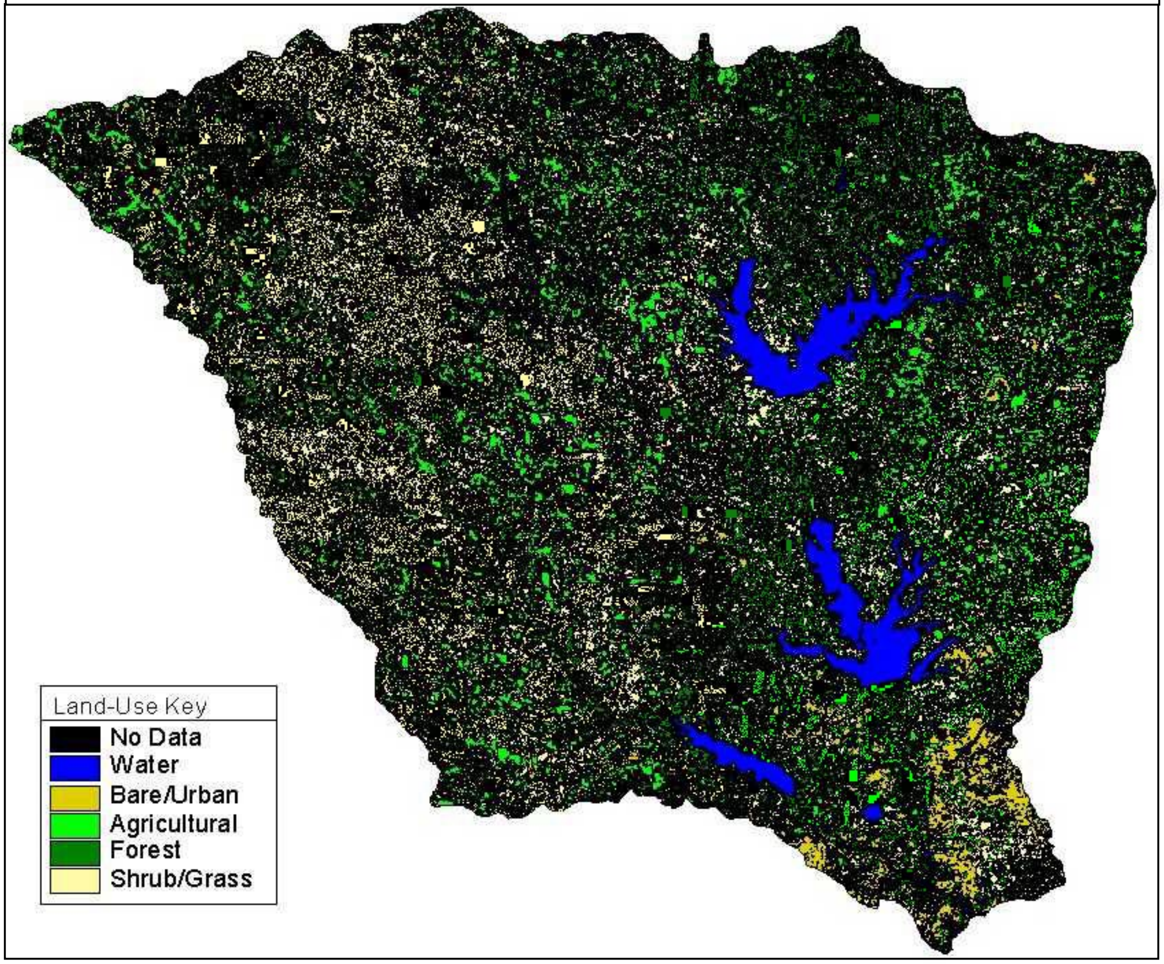
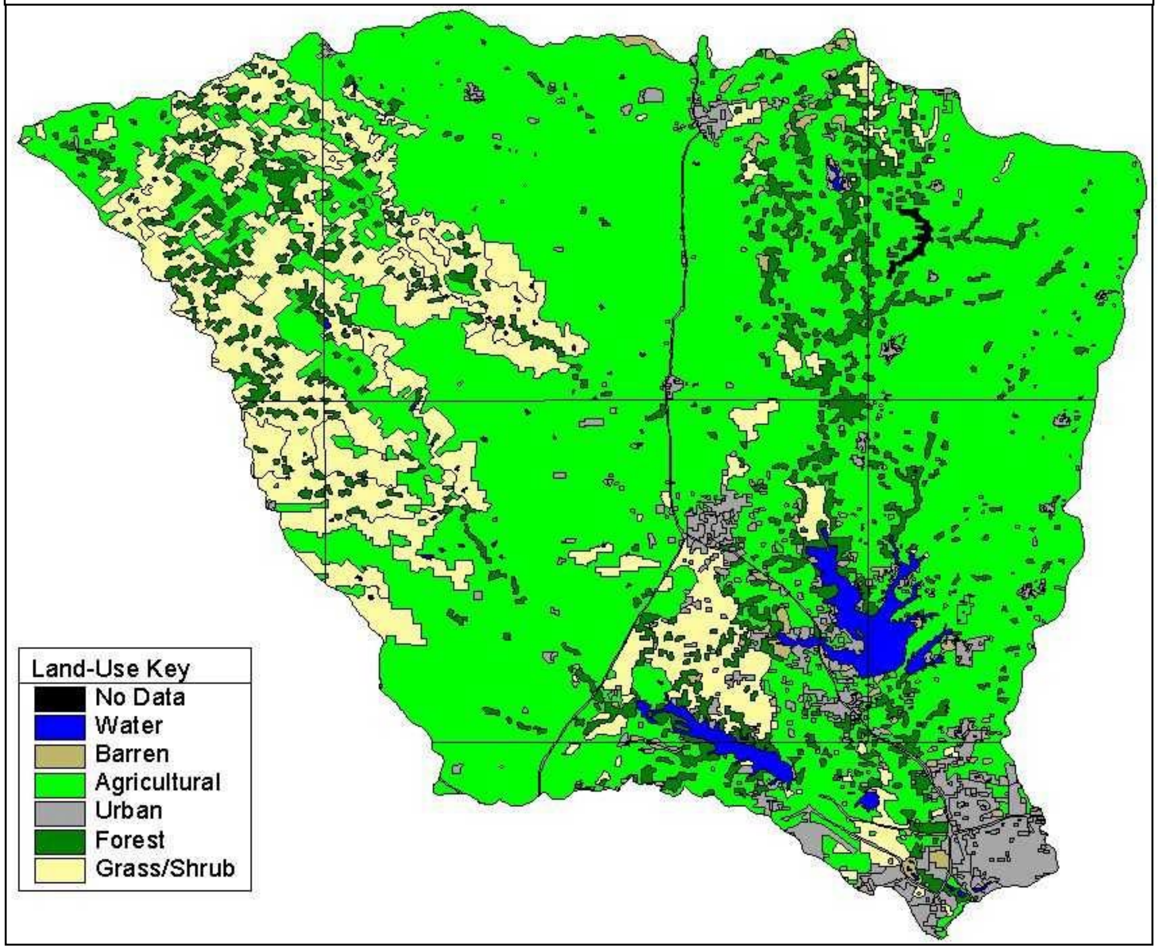


Table 14- BASINS Land-Use Classification Scheme and Recode			
Code	Classification	Recode	Reclassified
11	RESIDENTIAL	4	Urban
12	COMMERCIAL AND SERVICES	4	Urban
13	INDUSTRIAL	4	Urban
14	TRANS, COMM, UTIL	4	Urban
15	INDUST & COMMERC CMPLXS	4	Urban
16	MXD URBAN OR BUILT-UP	4	Urban
17	OTHER URBAN OR BUILT-UP	4	Urban
21	CROPLAND AND PASTURE	3	Agricultural
22	ORCH,GROV,VNYRD,NURS,ORN	3	Agricultural
23	CONFINED FEEDING OPS	3	Agricultural
24	OTHER AGRICULTURAL LAND	3	Agricultural
32	SHRUB & BRUSH RANGELAND	6	Grassland/Shrubland
41	DECIDUOUS FOREST LAND	5	Forest
42	EVERGREEN FOREST LAND	5	Forest
43	MIXED FOREST LAND	5	Forest
51	STREAMS AND CANALS	1	Water
52	LAKES	1	Water
53	RESERVOIRS	1	Water
61	FORESTED WETLAND	5	Forest
62	NONFORESTED WETLAND	1	Water
75	STRIP MINES	2	Barren
76	TRANSITIONAL AREAS	2	Barren

Figure 15—BASINS Land-Use Data



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